Journal of Forestry Research (2013) 24(3): 471–476
DOI 10.1007/s11676-013-0378-1

ORIGINAL PAPER

Growth performance and gum arabic production of *Acacia senegal* in northwest lowlands of Ethiopia

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Received: 2012-10-12; Accepted: 2013-02-22

Abstract: Despite the wide distribution of natural stands of *Acacia senegal* in Ethiopia, commercial exploitation of gum arabic is constrained by lack of tapping and development techniques. We evaluated the gum arabic yield from natural stands of *A. senegal* and the growth of 6 provenances in different parts of the country. For the gum yield evaluation from natural stands, four tapping positions and three tapping seasons were tested in a factorial RCB design. The second experiment in Metema evaluated survival and growth of six provenances. *A. senegal* trees in natural stands respond well to tapping if tapped during the appropriate season and at the correct position on the tree. The mean gum yield did not vary significantly by tapping season (p=0.63). Higher mean yield was, however, collected from trees tapped in October (96 g·tree^{-1} per two harvests). The mean yield differed significantly (p=0.009) between the tapping positions. Mean separation (α=0.05) shows that trees tapped at mid stem gave higher yield (160 g·tree^{-1} per two harvests). The interaction effect of tapping season and position was not significant. Higher mean yield ((70 ± 112) g·tree^{-1}) was recorded in mid October-mid stem in two harvests. The second experiment indicated statistically significant difference in mean survival (p=0.0298), height (p=0.000) and root collar diameter (RCD), (p=0.012) between the six provenances. Highest survival, height and root collar diameter growth was observed from Abderafi provenance (100%, (148±11) cm, (38±11) mm, respectively). We recommend October and mid-stem and branches as appropriate tapping season and position. We recommend planting of the Abderafi provenance for the study area due to its superior growth and survival. Our study contributes to the proper selection of provenances for plantation development and improved tapping technology for better production of gum arabic in the country.

Keywords: *A. Senegal*; *gum Arabic*; tapping season; position; provenances; growth performance

Fund project: This study was financed by the Ethiopian Institute of Agricultural Research.

The online version is available at http:// www.springerlink.com

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Introduction

Globally attention to Non-Timber Forest Products (NTFPs) has increased in the last three decades due to their compatibility with environmental objectives including the conservation of biological diversity, and their contributions to household economies, food security, and to national economies (Neumann and Hirsch 2000). NTFPs are biological resources of plant and animal origin, harvested from natural forests, plantations, woodlands and trees outside forests. Natural gums and resins are among the various NTFPs in the dry land resources that contribute to improved livelihoods of the many rural communities. Use of these resources poses little threat of environment degradation and thus leads to sustainable management and development of the dry lands. This supports their continued development and sustainable utilization.

Ethiopian dry land natural vegetation resources harbour several species of commercial potential. The dryland *Acacia-Commiphora* woodlands, dominated by *Acacia*, *Commiphora*, and *Boswellia* species, are well known for their economically valuable gum and resin products such as gum arabic, frankincense, myrrh (Eshete et al. 2005; Tadesse et al. 2007; Lemenih et al. 2011). The country is reported to be one of the world's largest producers of olibanum but the production of gum arabic is minimal (Tadesse et al. 2007; Lemenih et al. 2011).

Acacia senegal (L) Willd (family: Leguminosae, Mimosoidea) is a promising multipurpose tree species in arid and semi-arid areas of Ethiopia with various socioeconomic and ecological benefits (Azene et al. 1993; Jøker 2000). The species is highly valued for its production of gum arabic (Andreson 1990) from

trunks, branches and twigs. The species is an internationally designated source of gum arabic that is permitted for food use (Andreson 1995). The product has wide technological application in the food and pharmaceutical industries. In addition to gum, *A. senegal* trees improve soil fertility and are widely used to control desertification. The trees also provide fuel wood, local construction materials, and livestock fodder from leaves and pods. It is highly suitable in agroforestry systems, for its nitrogen fixing ability in combination with agricultural crops (Cossalter 1991).

A. senegal is a variable and widely distributed tree species, occurring in a range of subspecies and varieties (Ross 1979; Bernan 1983). The species has adapted to a wide ecological range that differs in rainfall, soil and altitude in arid and semi-arid areas of sub-Saharan Africa. It is naturally distributed in the traditional '*gum belt'* which occurs as a broad band across the sub-Saharan Africa, from Mauritania and Senegal in the west to Sudan, Eritrea, Ethiopia and Somali in the east. In Ethiopia, natural stands of *A. senegal* are found in the *Acacia*-*Commiphora* woodlands in the western, southern and southeastern lowlands and *Acacia* woodlands in the Rift Valley region (Azene et al. 1993). Varietal differences in *A. senegal* are based on variation in natural distribution as well as differences in morphological characteristics (Bernan 1983; Cossalter 1991). Four varieties of *A. senegal* are recognized- *A. senegal* var. *senegal*, var. *kerensis* Schweinf*,* var. *leiorhachis* and var. *rostrat* Bernan (Ross 1979) among which var. s*enegal*, var. *kerensis* and var. *leiorhachis* occur in Ethiopia (Azene et al. 1993). Commercial quality gum arabic is produced from *A. senegal* var. *senegal,* which is widely distributed on the African continent (Brenan 1983).

Despite the high potential of the resource base, the current annual production and export of gum arabic from Ethiopia is very low (Tadesse et al. 2007; Lemenih et al. 2011). This is due to the lack of proper production technique: current production is based mainly on collection of gum from natural oozes from tree trunks or branches. Moreover, knowledge of establishment techniques, yield and quality of gum from different provenances, optimum age for tapping, phenological records and silvicultural management requirements of the species are limited or lacking. Since *A. senegal* is an important cash crop for its valuable export product, there is interest in exploration and selection of provenances for gum arabic production. This research was designed to fill the gaps in knowledge and technology to properly utilize the potential of natural stands of the species and to promote selection of better performing and yielding provenances. Our specific objective were: (1) to investigate the effect of tapping position and season on gum yield, (2) to evaluate the gum yield of the species in the wild and develop tapping techniques for gum production, and (3) to investigate variation in growth of local *A. senegal* provenances and select provenances for further promotion.

Materials and methods

We carried out two experiments in the northwest lowlands of Amhara Region, at Merab Armachiho and Metema Districts. The first experiment aimed at evaluation of gum arabic yield from natural stands of *A. senegal* in Merab Armachiho (Abderafi area) tapped at different seasons and tapping positions. While, the second experiment conducted in Metema district to evaluate the survival and growth of six provenances of the species.

Description of the study area

The yield trial was conducted in natural *A. senegal* stands in Abderafi area, 985 km northwest of Addis Ababa. Elevation ranges from 550–950 m, asl. Annual rainfall is 885 mm and the mean annual temperature is 27.8 °C. The annual dry season averages 7 months in duration. The provenance trial was set up in Metema district at 36°17' E and 12°39 N' in North Gondar about 975 km northwest of Addis Ababa. The elevation ranges from 650–1100 m, asl. Mean annual rainfall ranges between 660–1130 mm. The mean minimum and maximum temperatures are 19.1 and 35.6 °C, respectively. Both areas are among the potential commercial crop production areas of the country.

Experimental design, data collection and analysis

A 3×4 factorial randomized complete block design with three replications was used for the yield trial. Two factors, namely tapping season and position of tapping were examined. The tapping seasons were three (mid October, mid November and mid December) whereas the tapping position had four levels: lower stem (50–100 cm), mid stem (100–150 cm), high stem (150–200 cm), and branches. Each treatment combination was applied to 5 trees in each block (60 trees per block for a total of 180 treated trees). The trees selected for the tapping experiment had almost uniform diameter. The selected 180 trees were tagged and treatment combinations were then applied. Tapping was done with a specially designed axe and "sunki". Trees were tapped in such a way to yield strips of relatively similar depth, width and length.

The first and second harvests from each experimental tree were collected manually. The gum yield from each harvest was collected in a separate labeled paper bag and weighed using a high precision balance after drying at room temperature. The yield data were analyzed using Analysis of Variance in SPSS.

The provenance trial was designed. Six local provenances of *A. senegal* were evaluated for variation in survival and growth in Metema District. The description of the provenances is presented in Table 1. The provenances were given names relating to their geographic origin (name of the area of collection followed by the seed zone number), following Albæk (1993). Although Wachile and Negele Borena are in the same seed zone, we consider them as separate provenances due to the observed morphological difference of the *A. senegal* trees.

A detailed account of the provenances/seed zones was given by Albæk (1993). Seeds were collected from selected mother trees that were at least 100 m apart. Seedlings were raised in Metema District Agricultural Office tree nursery, and were planted in a randomized complete block design (RCBD), (four replications with a total of 25 trees per plot at 4 m× 4 m spacing). The spacing between plots and blocks was 4 and 5 m, respectively. Survival counts were conducted one year after planting

while root collar diameter (RCD) and height of the inner plants were measured four years after planting. ANOVA was computed for the mean values of the observed variables using SPSS.

Table 1. *A. senegal* provenances and their corresponding seed zones

Provenance code	Collection area	Seed zone number according to Albæk (1993)
AD 11-3	Abderafi, North-west Amhara	11-3
AW6-1	Awash, Afar	6-1
Lan 10-1	Langano area, central Rift valley	10-1
NB9	Negele Borena	9
WAF-3.1	Worer, Afar	3-1
YB-9	Wachille, Yabello	9

Result and discussion

Gum yield from natural stands

The proportions of trees that yielded gum are listed by tapping position and season in Table 2. The proportion of trees that produced gum was highest (66.7%) for October tapping at tree branches. The lowest proportion of trees producing gum was recorded for trees tapped in October and November at the low trunk position. Overall, October tapping and branch tapping resulted in the highest proportions of gum producing trees, 45.1% and 48.9%, respectively. This might have been the trees start to shade their leaves and translocate the carbohydrates from their leaves to branches in early October.

Table 2. Proportion of trees that yielded gum in response to tapping (data from 2001 tapping and yield)

Season	Branch (%)	High stem (%)	Mid stem (%)	Low stem (%)	Mean (%)
Oct	66.7	60.0	53.5	0.0	45.1
Nov	53.3	21.3	26.7	0.0	25.3
Dec	26.7	46.7	13.3	6.6	23.3
Mean	48.9	42.7	31.2	2.2	31.2

Effect of tapping season and tapping position on gum yield

Gum yield was highly variable by tapping season and tapping position and among trees that were tapped in the same season at the same position. Considering only those trees that produced gum, the maximum yield was 368 g·tree^{-1} in the first two harvests while the lowest was 1 g·tree^{-1}. The mean yield of gum per tree in the first two harvests differed significantly between tapping position levels (p =0.009) but not between tapping seasons (p =0.63) (Table 3). No interaction effect on gum yield was observed between tapping season and position (p =0.252).

Tapping in October yielded more gum ((96.46±20) g·tree^{-1}) in the first two harvests. The lowest yield was recorded for December tapping at (45 ± 18) g·tree^{-1}. Fig. 1 presents the mean gum yield of the first two harvests for the three tapping seasons. The yield was higher than the yield from natural stands (36 g·tree^{-1} per two harvests) and farm gardens (55 g·tree^{-1} per two harvests) reported from the Sudan (Ballal et al. 2005). Yield was comparable with experimental natural stands (98 g·tree^{-1} per two harvests) but lower than the yield from experimental plantations (123 g·tree^{-1} per two harvests). Mean yield from October tapping was greater than from November tapping and significantly greater than from December tapping. Thus, October tapping proved appropriate season to commence tapping for highest yield.

Table 3. ANOVA of mean gum yield of *A. senegal* trees

Source	Type III Sum of Squares	*df*	Mean Square	*F*	Sig.
Corrected Model	468.439[a]	9	52.049	3.505	0.003
Intercept	1051.267	1	1051.267	70.797	0.000
Season	13.882	2	6.941	0.467	0.630
Position	201.146	3	67.049	4.515	0.009
Month * Position	83.368	4	20.842	1.404	0.252
Error	549.413	37	14.849		
Total	3941.960	47			
Corrected Total	1017.852	46			

Notes: a. R Squared = 0.460 (Adjusted R Squared = 0.329).

Table 4. ANOVA for survival percentage of provenances of *A. Senegal*

Source	Type III sum of squares	d*f*	Mean square	F	*P*-value
Provenance	4054.33	5	810.867	3.22	0.0298
Within groups	4527.5	18	251.528	-	-
Total (Corr.)	8581.83	23	-		-

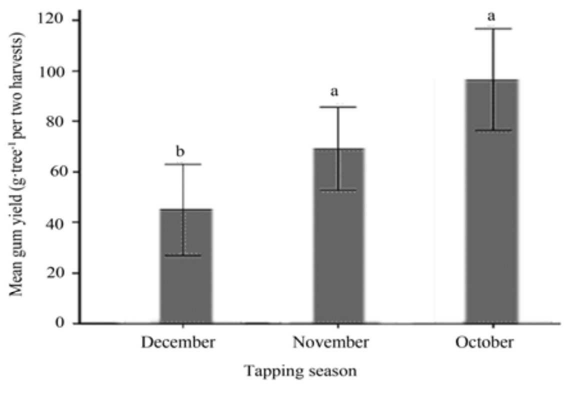

Fig. 1 Gum arabic yield from three tapping seasons

The yield from mid-stem tapping was significantly greater than from other tapping positions (Fig. 2). The mid stem position gave a mean yield of (154.8±29) g·tree^{-1}, higher than the highest yield (110.7 g·tree^{-1}) reported in Sudan from the first two harvests (Adam and Fadl 2011).

The combined yield from the first and second harvests of gum is highly correlated with total yield and taken as a direct indicator of total annual yield per tree (Ballal 2002; Ballal et al. 2005). This yield can be used to predict total yield per tree in a given year and future years by taking into account the temperature, rainfall, tapping season and intensity of tapping. Our study considered the gum yield only of the first two harvests due to the location of the research area and difficulty of access. Overall, the gum yield in the first two harvests of our study was comparable with that reported from the Sudan by Ballal (2002), Ballal et al. (2005) and Adam and Fadl (2011).

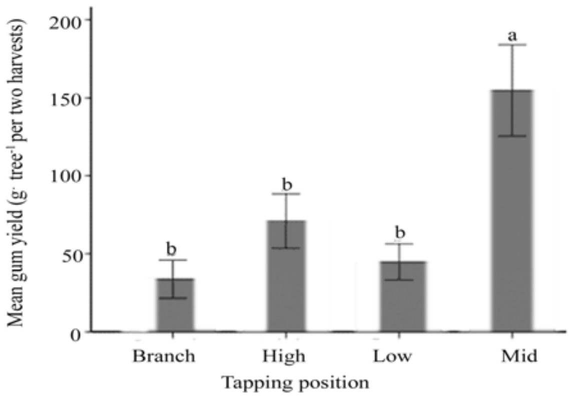

Fig. 2 Gum arabic yield from four tapping positions

Survival, RCD and Height of *A. senegal* provenances

Survival, diameter and tree height are important indicators of adaptability and performance evaluation in the evaluation of species and provenances (Ræbild 2002). Although, the primary purpose of provenance evaluation was for gum yield, the early performance of provenances in terms of survival, root collar diameter and height was evaluated to select the best performing provenance for establishment of plantations in the northwest lowlands of Amhara.

Survivals

Survival one year after planting ranged from 61%–100%, the lowest survival was for the Central Rift valley (LAN 10-1) provenance and the highest for Abderafi (AD 11-3) provenance (Fig. 3). High variability in survival was observed between blocks of the LAN 10-1, WAF3-1 and NB9 provenances. Survival varied significantly (p=0.0298) between provenances (Table 4).. This could be explained by the genetic and environmental variability of the species (Ross 1979).

Height and root collar diameter (RCD)

Tree heights and root collar diameters were highly variable among the provenances tested. Significant differences were observed between provenances in tree height (p=0.000) and root collar diameter (p =0.012) (Table 5). Overall mean height was (113±5) cm, while mean root collar diameter was (28±1) mm after four years of growth. Greatest height ((148±11) cm) and RCD ((38±11) mm) were recorded for the Abderafi provenance (AD11-3) followed by the Central Rift Valley (LAN10-1). Lowest height ((80±5) cm) and RCD ((17±0.8) mm) were recorded for Yabelo (YB9) provenance (Table 6). The height and diameter growth of the species at the trial site indicate its suitability for small and large scale plantation.

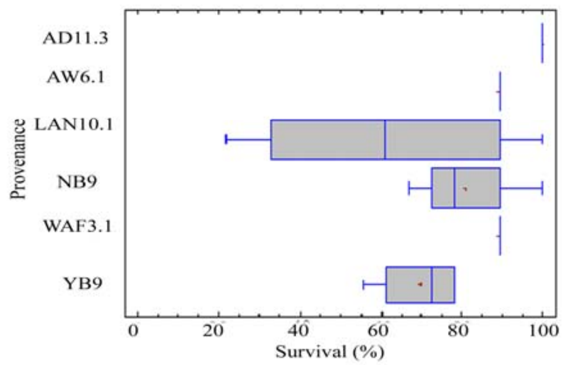

Fig. 3 Inter-provenance variation of survival percentage

Table 5. ANOVA of height and root collar diameter (RCD) of provenances of *A. senegal*

Index	Source	Sum of Squares	*df*	Mean square	F	*p*
Height	Between Provenance	266323.973	5	53264.795	16.646	0.000
	Within provenance	623957.969	195	3199.784		
	Total	890281.942	200			
RCD	Between Provenance	2434.052	5	486.810	3.016	0.012
	Within provenance	31470.764	195	161.389		
	Total	33904.816	200			

Table 6. Mean heights and root collar diameters (RCD) of provenances of *A.senegal*

Index	Provenance	Mean	Std. Deviation	Std. Error of Mean	CV%
Mean height (cm)	AD11-3	148	62.3	10.7	42.1%
	AW6-1	107	43.6	7.8	40.5%
	LAN10-1	134	86.1	20.3	63.9%
	NB9	92	42.8	9.4	46.3%
	WAF3-1	104	50.1	9.0	47.8%
	YB9	80	22.7	5.1	28.1%
	Total	**113.6**	**57.9**	**4.7**	**50.9%**
Mean RCD (mm)	AD11-3	38	10.6	1.8	28.4%
	AW6-1	28	9.0	1.6	32.7%
	LAN10-1	32	20.6	4.8	63.8%
	NB9	27	10.2	2.2	38.3%
	WAF3-1	22	8.6	1.5	39.4%
	YB9	17	3.5	0.8	20.3%
	Total	**28**	**12.7**	**1.0**	**45.8%**

Research on the patterns of natural variation in commercially and adaptively important traits is essential to develop tree improvement and plantation development for native species of commercial importance. This is particularly urgent for *A. senegal* for commercial production of gum arabic to meet international demand. There has been little systematic research on provenance variation in growth and survival of *A.senegal* species in Ethiopia. Initiatives for *A. senegal* plantation establishment for gum arabic production tend to seek germplasm from abroad (eg. Sudan) since the local varieties are considered to be of inferior quality for gum production. However, the present study revealed that *A. senegal* trees respond well to tapping and could yield comparable quantities of gum arabic. The observed survival and growth may qualify Abderafi AD11-3 provenance as a potential seed source for establishment of *A. senegal* plantations in the northwestern lowlands of Amhara region sharing climatic and ecological condition similar to those of the Metema area.

Conclusions and recommendation

The present study demonstrated the possibility of gum production from natural stands of *A. senegal*. Gum yield was highly variable among trees and was affected by tapping season and tapping position. Yields recorded in our study were comparable to those reported for the Sudan, the leading producer of gum arabic. Thus, tapping trees during the appropriate month and at the appropriate position can enhance the production of gum arabic from natural stands of *A. senegal*. Generally, we recommend tapping of branches starting from October when the leaf color begins to change. Although the yield per tree from mid stem position was higher, we recommend tapping the branches in order to minimize damage to trees and to maximize yield by tapping many branches. Although, there are many other factors that might affect gum yield per tree in natural stands of *A. senegal*, the present study considered only two: month of tapping and the position where tapping should be done. Moreover, the yield from only the first two harvests was considered in this study although gum can be harvested up to 10–12 times at intervals of 15 days after the first tapping without refreshing the wound. Thus we recommend further research to consider more variables in all harvests. This can be properly conducted in permanent trial plots so as to integrate other ecological studies related to the species.

Survival, diameter and height growth were highly variable between and within provenances of the species. This might be due to the genetic and environmental variability of the species. Best survival and diameter and height growth were recorded for Abderafi AD11-3 provenance. Thus, this provenance is recommended for the area surrounding the trial site.

We expect that promotion of gum arabic tapping and production techniques and development of plantations in pure stands as well as incorporation with dryland farming systems will contribute to rural livelihood improvement and to the national economy, and will yield environmental benefits, including land rehabilitation. These benefits are in line with the current economic development strategy, Agricultural Development Lid Industry (ADLI) and export based production system and import substitution, of Ethiopia. In the face of growing international demand for gum arabic, investing in the development and promotion of appropriate production and management techniques of the vast natural stands of *A. senegal* in the country and establishment of commercial plantation will be highly rewarding.

Acknowledgements

The research was financed by the Ethiopian Institute of Agricultural Research. The authors acknowledge the technical assistant and inputs from researchers and technicians in the Forestry Research Centre and Gondar Agricultural Research Centre. We would like to acknowledge the provision of experimental field from Metema and Merab Armacho District Agricultural and Rural Development Offices.

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